NASA Technical Memorandum 101514

The Versatility of a Truss Mounted Mobile Transporter for In-Space Construction

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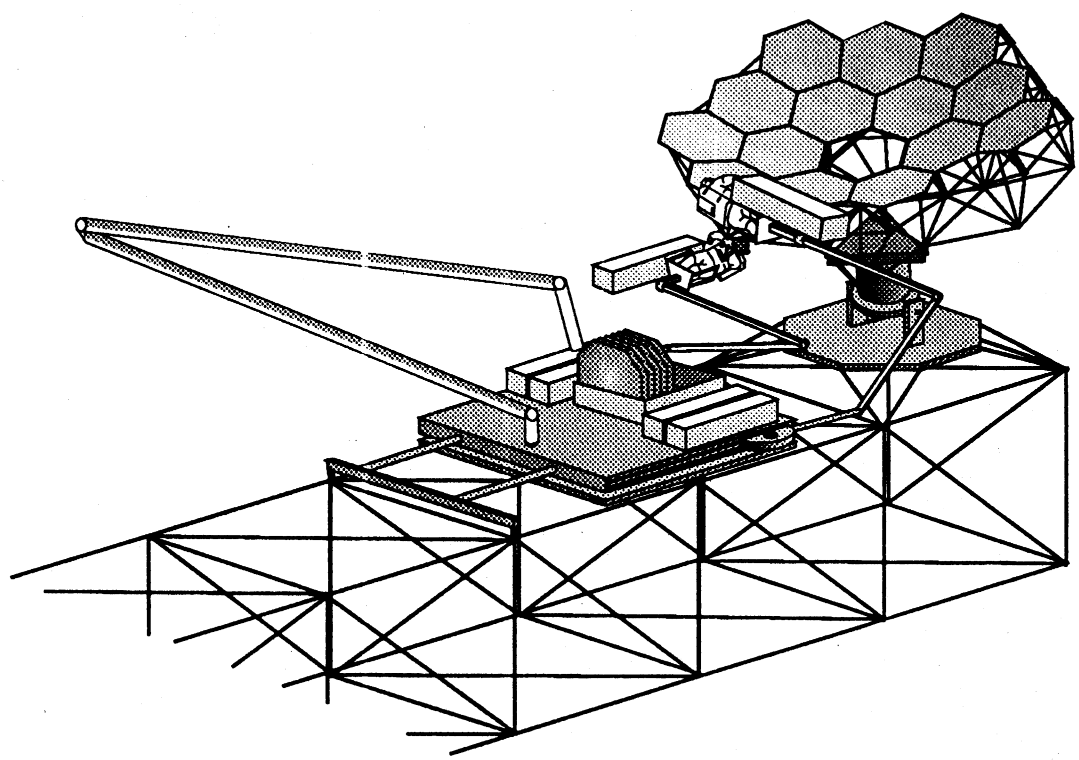
November 1988



NASA
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THE VERSATILITY OF A TRUSS MOUNTED MOBILE TRANSPORTER FOR IN-SPACE CONSTRUCTION

Harold G. Bush, Mark S. Lake, Judith J. Watson, and Walter L. Heard, Jr.

INTRODUCTION

The NASA Langley Research Center (LaRC) has studied the design and construction of large space structures extensively (References 1-4). From these studies, the erectable structures concept emerged, whereby large truss structures such as platforms or curved reflectors are erected or assembled from individual struts and nodes. The compact stowage capability of erectable structures is considered highly desirable, when compared to the voluminous packaging required by large deployable trusses. In addition to developing the structural design technology necessary for lightweight, efficient space platforms, methods had to be devised for efficiently assembling dozens, hundreds, and perhaps thousands of struts and nodes. Studies have been conducted on techniques ranging from unaided Extra-Vehicular Activity (EVA) to fully automated assembly of large platforms (References 5 and 6). Unassisted EVA was found to be inefficient for assembling large structures due primarily to the highly fatiguing translation required, and the inability to hold a position at an assembly site due to the lack of foot restraints. Fully automated assembly, using dedicated assembly hardware, was found to be possible but probably not needed, except for very large structures.

A method was developed which largely eliminated the undesirable aspects of unassisted EVA assembly without incurring the cost of automated assembly. This method is referred to as a mobile work station in Reference 7 and is shown being used in neutral buoyancy tests (simulated 0-g) in Figure 1. The mobile work station positioned the astronauts in foot restraints at a work station which provided translation within a prescribed work envelope. Thus, the astronauts were relieved of fatiguing translation and were also provided with a mechanism to react forces and moments incurred during manipulation or assembly of the structural elements - an extremely important feature. Working cooperatively, two astronauts were found to be very efficient building truss segments using 18-foot-long struts. When completed, a segment of the truss was translated out of the work envelope to permit the addition of another segment, or bay. This process was repeated until the desired structure was completed. Average unit assembly times of approximately 38 sec/strut were achieved from repeated tests. Another version of a mobile work station, presented in Reference 8 and shown in Figure 2, was configured to permit a single astronaut to assemble long booms using 5-6 ft struts . This device, referred to as a swing arm beam erector, moved an astronaut around the beam and along its length a distance of one bay. This permitted achieving unit assembly times of approximately 28 sec/strut assembling long beams.

These studies have identified efficient ways of assembling large structures in EVA. However, the advent of Space Station extended the list of EVA operations which astronauts must be capable of performing, even if in a secondary or backup mode. It is the purpose of this paper to describe the versatility of a device, known currently as a Mobile Transporter (MT), which greatly enhances the efficiency of the astronaut in performing the EVA tasks required to build and maintain the Space Station. Properly configured, the MT will also provide an enabling capability to assemble spacecraft for missions beyond Space Station.

MOBILE TRANSPORTER (MT) FEATURES

Very early during the Space Station development period, the need was identified for a logistics device that would support the astronauts performing EVA operations (References 9 and 10). It was determined that this device, shown in Figure 3, should possess mobility to transport men and materials (i.e., truss components, pressurized modules, payloads, etc.) around the Space Station. The functional requirements of multi-directional translation, plane change capability and positioning capability for astronauts and equipment were identified.

Multi-Directional Mobility

The ability to move in two orthogonal directions is required to assemble and service the dual keel Space Station configuration. Translation parallel to the transverse boom is needed to install and service the power systems and translation perpendicular to it is needed to reach payloads mounted on the upper and lower keels. Rail mounting of this device is considered possible but highly impractical due to the added mass and structural complexity. A transporter mobility system which has the tracks mounted on the transporter and connects to the truss nodes using guidepins is shown in the exploded sketch of the entire MT in Figure 4, and separately in Figure 5.

Movement of the square track system in two orthogonal directions without disconnecting from the truss is permitted by rotating corner switches which are shown in Figure 5. A drive system which provides mobility to the MT is shown in Figures 3 and 6. This sequential drive system, as configured, provides 360 degrees rotation of the drawbar and permits movement by "pushing" or "pulling" the MT, one bay at the time, in either of two orthogonal directions. A sketch of one corner switch - drawbar drive rod arrangement is shown in Figure 7, which illustrates how the track system and drawbar connect to the same guidepin. Not shown in Figure 7 is a clamping device which locks the drawbar to the guidepin through the corner switch.

Plane Change

A required feature of the MT is the ability to operate on either of two sides of the Space Station truss structure. Thus, a means for the MT to change planes must exist. Two possible methods, involving truss modification, are presented in Reference 10. Other methods which locate the plane change mechanism on the MT have been recently identified. Development of this capability for the MT is necessary to permit locating this device (and the astronauts) anywhere it can be utilized.

Astronaut Positioning System (APS)

Assembly tests (References 7, 8, and 11) have demonstrated the utility of providing a positioning capability to the astronauts during EVA assembly activities. This is accomplished with an astronaut positioning system (APS) shown in Figure 8. This system, which provides translation and positioning within each astronauts work envelope, does not need the operational positioning accuracy requirements of the shuttle RMS. Control of the APS should reside with the astronaut. Pre-programmed positions with vernier adjustment would allow different sized astronauts to adjust their work location for comfort and ease. The operational degrees of freedom of the APS shown in the figure are those identified to date as being necessary. Others will be determined by the usage of the MT. Ongoing studies in the Space Station, Pathfinder, and Precision Segmented Reflector technology development programs are expected to define the required operational degrees of freedom for an APS.

Remote Manipulator System (RMS) Base

A primary function of the MT is to transport payloads and system components around the Space Station. Some of these components will be too large for astronauts to install without assistance. During Space Station construction, large pressurized modules must be attached to the truss. A relatively straightforward method of attachment consists of using appropriately sized Space Station strut and joints to connect the modules to the truss structure. A transposed shuttle RMS or a Space Station RMS (see Figure 8) would be used to position the module, while astronauts position themselves, using the APS, to effect the structural connections. Control of the MT based RMS should be effected by an astronaut in foot restraints, using a portable control panel, in much the same manner as overhead cranes are operated on Earth. This permits the astronaut closest to the connection to control movement of the component being attached. Such a scenario (see Figure 9) illustrates the potential of this system to eliminate complex intermediate, deployable truss connectors by using existing struts and joints which are common with the Space Station structure. Similar scenarios are possible for the installation of payloads and/or other required equipment. A mobile transporter based RMS, properly located, is a necessary, logical extension and application of developed Shuttle and Space Station RMS technology and hardware.

MOBILE TRANSPORTER VERSATILITY

With the operational features described herein, a Mobile Transporter becomes a powerful tool for enhancing the EVA capability and productivity of astronauts. Reference 12 describes, conceptually, the features of a integrated orbital construction facility. One proposed feature is a large "logistics depot" similar to a maritime dry dock where large interplanetary spacecraft would be assembled from components brought up from Earth. Such a facility is shown in Figure 10. The facility consists of "scaffolding" assembled by astronauts from developed Space Station truss components using the MT. An important feature of this facility is the highly maneuverable space crane also shown in Figure 10. This space crane would be used to transfer and position spacecraft components and material from the Shuttle cargo bay into the construction site for assembly into a large spacecraft (i.e., Mars vehicle). Additionally, the MT mounted RMS would serve as an end effector to position components for assembly, in conjunction with astronauts using the APS to effect final equipment installation. If so desired, the entire spacecraft assembly complex could be easily dissassembled and restowed or reconfigured to meet the requirements of future missions.

SUBMILLIMETER ASTRONOMICAL LABORATORY

One future mission being studied which requires on-orbit spacecraft assembly, due to its size, is a submillimeter-astronomical laboratory shown conceptually in Figure 11. This device incorporates a near optical quality reflector surface, made up of precise segments - each of which is actively controlled to maintain overall accuracy. The active control system requires an accurate, stable and stiff foundation, which is achievable through use of a truss structure.

Reflector Assembly Time

One method being investigated for assembling the entire spacecraft also includes assembling the truss via EVA. A sketch of the truss assembly and surface facets is shown in Figure 12. This structure contains 789 tubular struts, each approximately 2-meters in length, 198 nodes, and 90 precision hexagonal facets, approximately 2-meters in diameter. Based on past experience (References 8 and 13) the struts and nodes alone could be manually assembled in approximately 3.5 hours by two astronauts or 6 ours by one astronaut. Installation of the 90 surface facets and an active control system wiring harness could add considerably to this time. Figure 13 shows estimated assembly times for the truss and facets as a function of the time required to install one facet and its associated wiring. The vertical bandwidth is based on actual one and two man test experience to date in either neutral buoyancy or on-orbit truss construction. It is noted that the orbital EVA assembly rate which was achieved during the ACCESS flight test using similar size struts (Reference 13) was approximately the same as that achieved during neutral buoyancy tests. The horizontal bandwidth is the result of considering various EVA facet/wiring installation methods with or without RMS assistance, and estimating the installation time for each method. The overlapping bandwidths bound the best estimate of EVA time required to assemble the reflector portion of this submillimeter astronomical laboratory. It is shown in Figure 13, that the fastest reflector assembly times are achieved with two astronauts without RMS facet installation assistance. It is also noted that EVA assembly of the truss, with a high part count (789 struts and 198 nodes), requires only a fraction of the total assembly time (14 percent). The 90 reflector facets represent the smallest part count but due to their nature (size, complexity and fragility) require the majority of the estimated reflector assembly time (86 percent). Assembly times for other parts of the entire spacecraft will have to be added to the time shown in Figure 13 as designs and assembly techniques for these components are developed.

Reflector Assembly Method

The technique being examined for assembling the large, faceted truss reflector is shown in Figure 14. A payload pallet, supporting a rotating spacecraft cradle, is shown in position at an appropriate location on Space Station. The MT serves as a movable base, supporting and positioning astronauts to enable the assembly of struts, nodes and facets, a supply of which is positioned nearby on the MT. As each "ring" of facets and supporting truss is added to the rotating assembly, the MT translates radially outward from the rotational center to permit the installation of the next ring. The cradle provides tilt, as well as rotation, to the reflector to maintain the construction site within reach of the MT and astronauts. The astronaut positioning capability of the MT is essential to efficiently assemble components of the reflector.

MOBILE TRANSPORTER STATUS

Langley Research Center (LaRC) is continuing development of the MT assembly approach for large space structures. A 5-meter erectable truss was selected as Space Station baseline structure, on the basis of using a MT with an APS to support two astronauts in EVA for assembly of the Station. The in-house LaRC research program in large space structures assembly has been focused toward the Space Station truss to demonstrate the utility of a MT and to provide a test device which could be used to examine structural assembly problems and provide realistic training to pressure suited astronauts. A MT laboratory test article, with limited capability, is shown in Figure 15. This MT mock-up has an operable drawbar to index each bay of truss as it is completed and an operable APS for each astronaut. The MT test article positions the astronauts with their heads toward the MT platform due to 1-G safety concerns. This is opposite the preferred orbital orientation as shown in the inset of Figure 15. Relative motion between the MT and truss structure is accomplished by supporting the MT and moving the lower mass truss. A test program for this device is detailed in References 11, 14, and 15. This test program investigated use of the MT to erect several bays of Space Station truss structure, including installation of the utility trays. Laboratory 1-G tests were conducted at LaRC to provide equipment operational checkout and establish assembly procedures. A photograph of the 1-G test setup is shown in Figures 16a and 16b. The 1-G tests did not include utility tray installation. The entire test apparatus was subsequently moved to Marshall Space Flight Center (MSFC) and installed in the Neutral Buoyancy Simulator (NBS) tank. A series of assembly tests were conducted, including installation of the utility trays. The underwater test setup with the trays in position attached to the truss is shown in Figures 17a and 17b. Average assembly times of approximately 28 seconds/strut were repeatedly obtained using well-trained engineers to assemble three bays of truss. Installation of the deployable utility tray concept had an insignificant influence on assembly time.

CONCLUDING REMARKS

The operational and mechanical features of a Mobile Transporter which supports EVA construction have been described. Additionally, a discussion has been presented on application of the MT to the construction of many structures and spacecraft whose assembly appears very impractical without a MT to support astronaut EVA. Test results from Space Station assembly by space-suited subjects in neutral buoyancy are presented which clearly identify the utility of a MT. Significant improvement in astronaut EVA assembly capability and efficiency were demonstrated in these tests as a result of having a MT based astronaut position system. Furthermore, study has shown that a MT based RMS is necessary to accomplish many proposed missions.

Clearly, the body of evidence gathered to date is persuasive that a Mobile Transporter with features described herein is the necessary versatile component that makes orbital spacecraft assembly practical and possible.

REFERENCES

1. Bush, Harold G.; and Mikulas, Martin M., Jr.: A Nestable Tapered Column Concept for Large Space Structures. NASA TM X-73927, 1976.

2. Mikulas, Martin M, Jr.; Bush, Harold G.; and Card, Michael F.: Structural Stiffness, Strength, and Dynamic Characteristics of Large Tetrahedral Space Truss Structures. NASA TM X-74001, 1977.

3. Bush, Harold G.; Mikulas, Martin M, Jr.; and Heard, Walter L., Jr.: Some Design Considerations for Large Space Structures. AIAA Journal, Vol. 16, No. 4, April 1978, pp 352-359.

4. Heard, Walter L., Jr.; Bush, Harold G.; Walz, Joseph E.; and Rehder, John J.: Structural Sizing Considerations for Large Space Platforms. Journal of Spacecraft and Rockets. Vol. 18, No. 6, November - December 1981, pp 556-564.

5. Jacquemin, G. G.; Bluck, R. M.; Grotbeck, G. H.; and Johnson, R. R.: Development of Assembly and Joint Concepts for Erectable Space Structures. NASA CR-3131, 1980.

6. Bement, Lawrence J.; Bush, Harold G.; Heard, Walter L., Jr.; and Stokes, Jack W., Jr.: EVA Assembly of a Large Space Structure Element. NASA TP-1872, 1981.

7. Heard, Walter L., Jr.; Bush, Harold G.; Wallsom, Richard E.; and Jensen, J. Kermit: A Mobile Work Station Concept for Mechanically Aided Astronaut Assembly of Large Space Trusses. NASA TP-2108, 1983.

8. Watson, Judith J.; Heard, Walter L., Jr.; and Jensen, J. Kermit: Swing-Arm Beam Erector (SABER) Concept for Single Astronaut Assembly of Space Structure. NASA TP-2379, 1985.

9. Mikulas, Martin M., Jr.; et al: A Manned-Machine Space Station Construction Concept. NASA TM 85762, 1984.

10. Bush, Harold G.; Mikulas, Martin M., Jr.; Wallsom, Richard E.; and Jensen, J. Kermit: Conceptual Design of a Mobile Remote Manipulator System. NASA TM 86262, 1984.

11. Heard, Walter L., Jr.; et al: Results of EVA/Mobile Transporter Space Station Truss Assembly Tests. NASA TM 100661, November 1988.

12. Mikulas, Martin M., Jr. and Dorsey, John T.: An Integrated In-Space Construction Facility for the 21st Century. NASA TM-101515. November 1988.

13. Heard, Walter L., Jr.; et al: Results of the ACCESS Space Construction Shuttle Flight Experiment. AIAA Space Systems Technology Conference, San Diego, June 9-12, 1986.

14. Heard, Walter L, Jr.; et al: Astronaut/EVA Construction of Space Station. AIAA SDM "Issues of International Space Station" Conference, Williamsburg, April 21-22, 1988.

15. Heard, Walter L., Jr.; Bush, Harold G.; and Watson, Judith J.: Space Truss Construction Studies. ASCE "Space 88 - Engineering, Construction, and Operations in Space" Conference, Albuquerque, August 29-31, 1988.

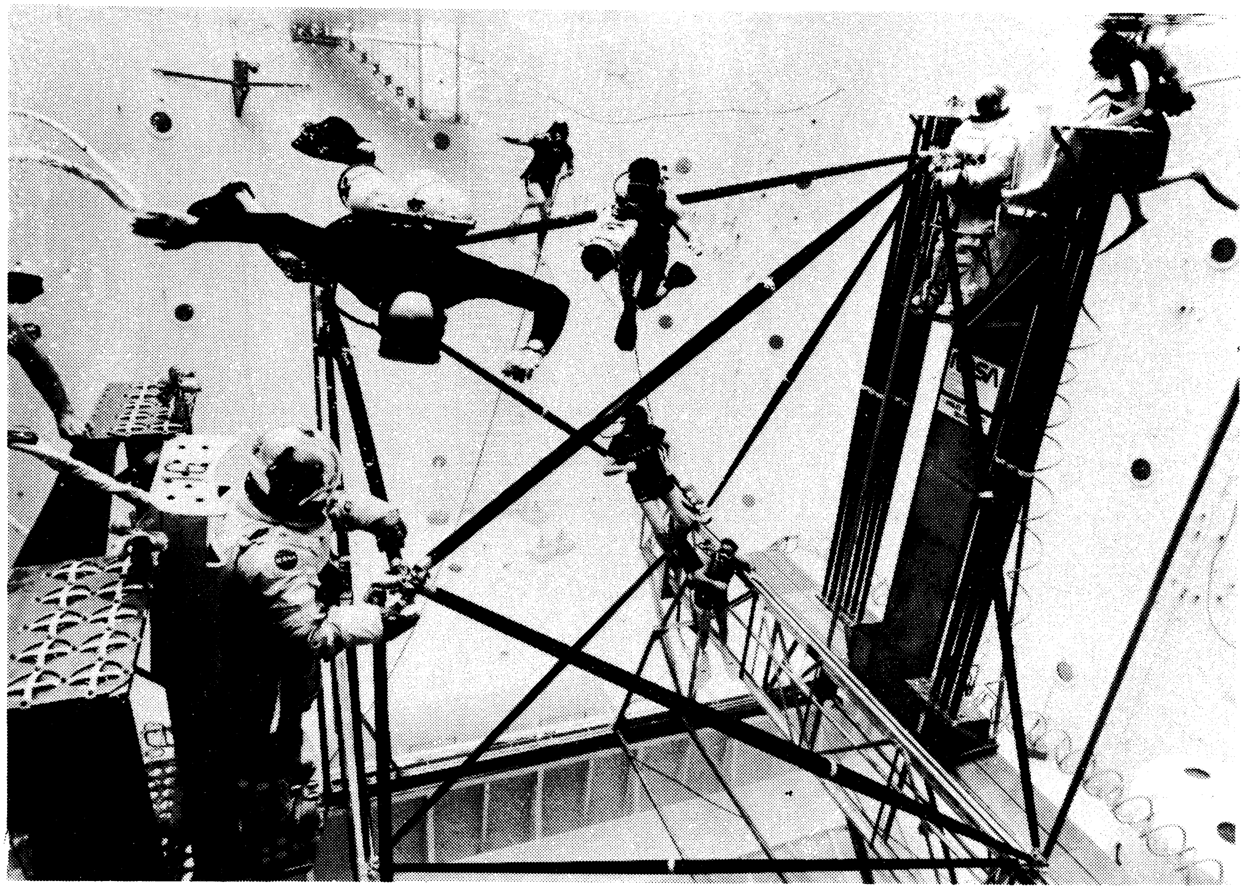


Figure 1. - Mobile Work Station structural assembly test in neutral buoyancy.

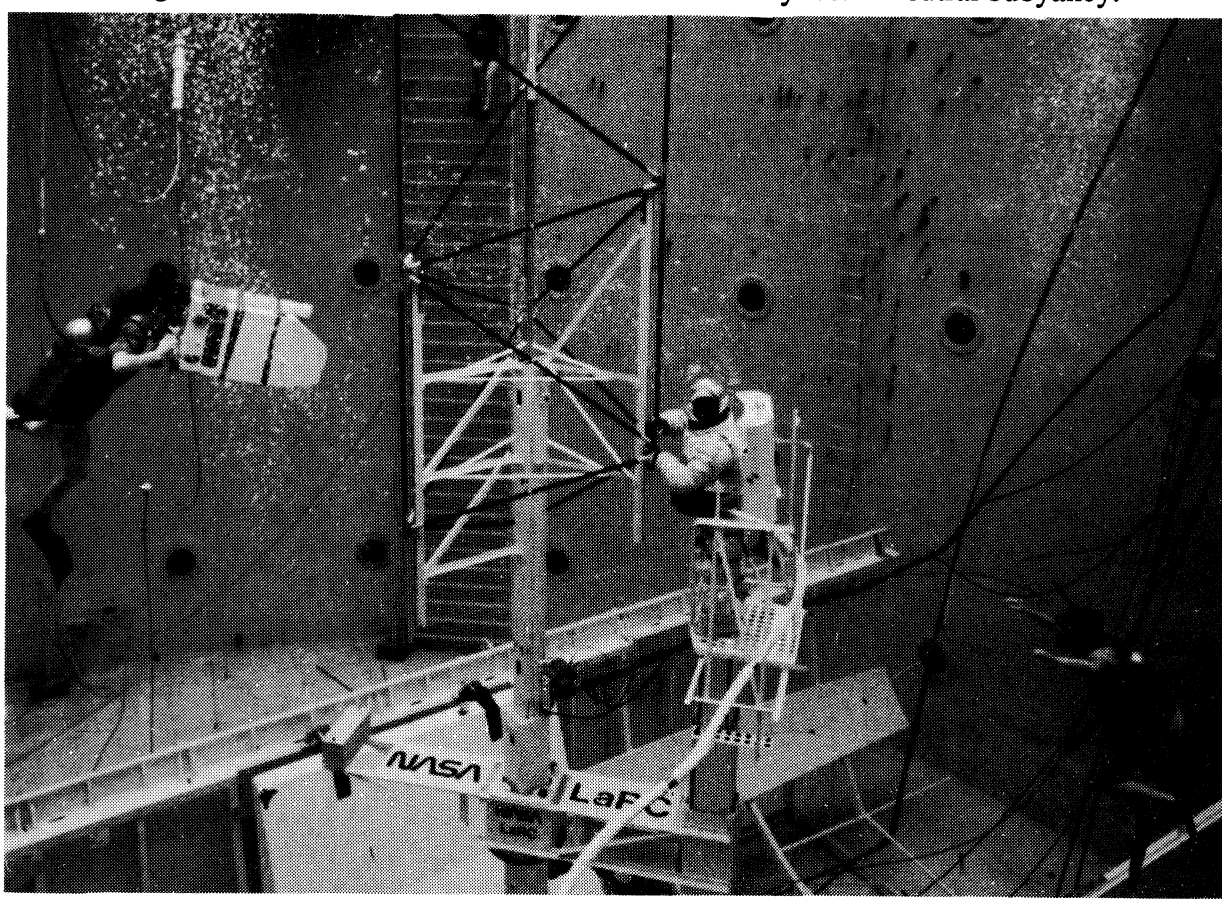


Figure 2. - Swing Arm Beam Erector (SABER) structural assembly test in neutral buoyancy.

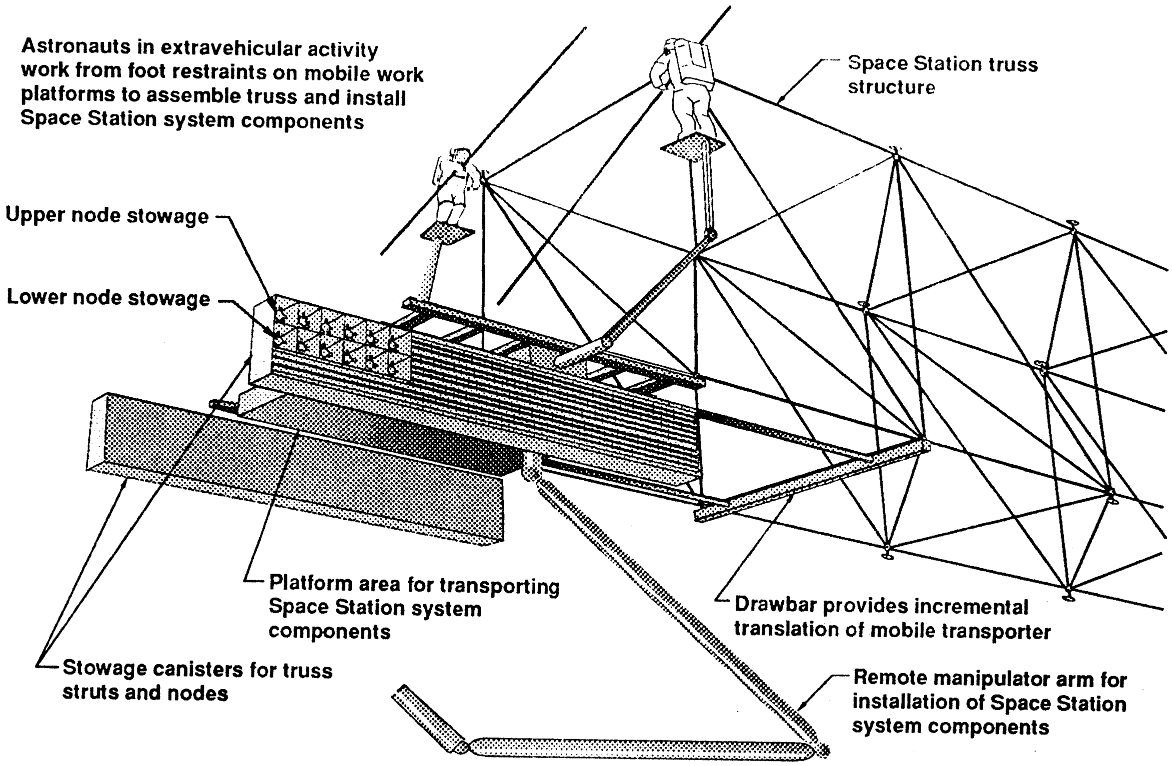


Figure 3. - Space Station assembly using Mobile Transporter.

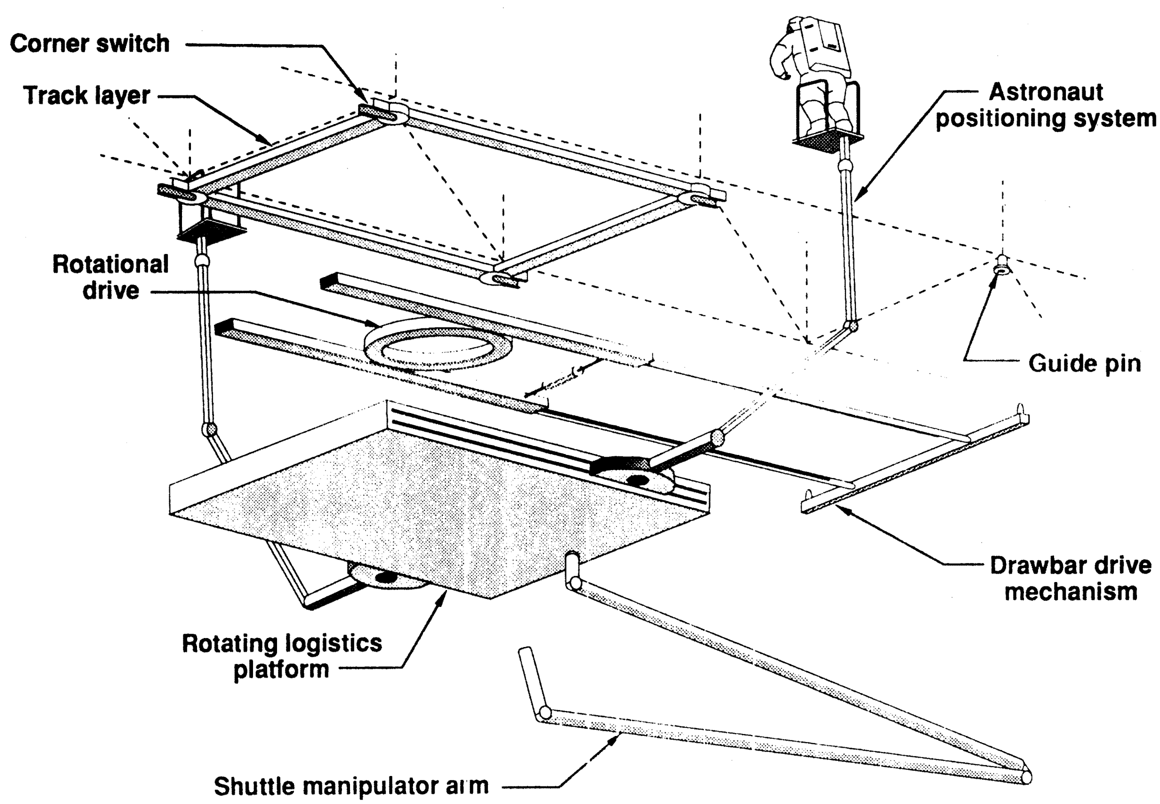


Figure 4. - Mobile Transporter elements (exploded view).

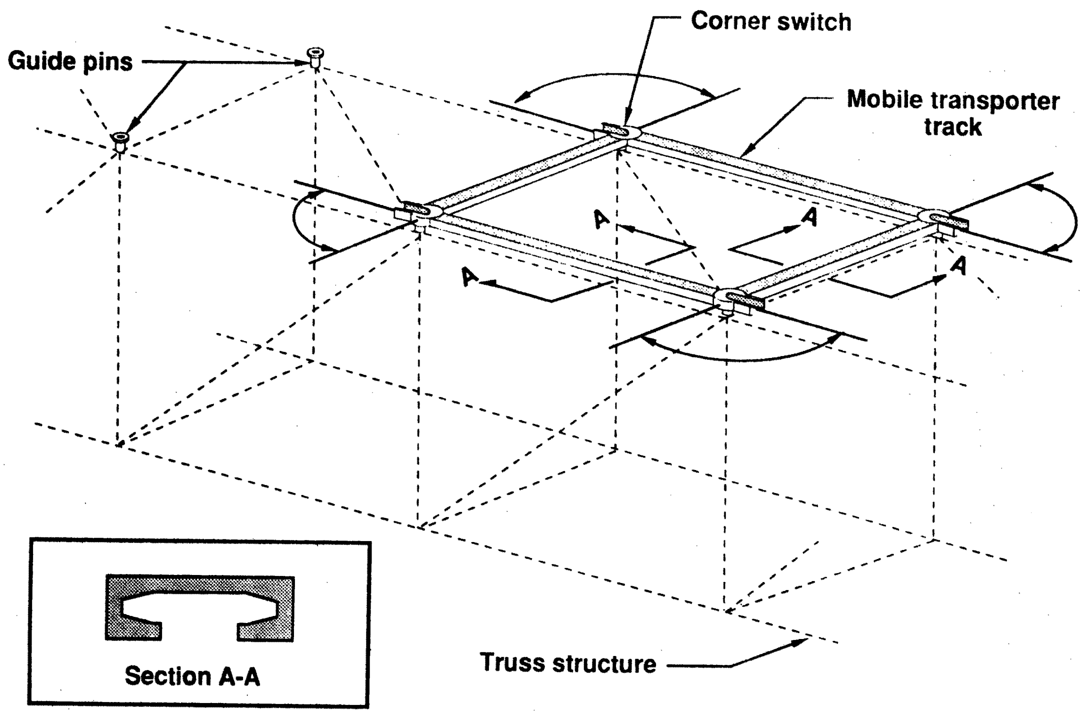


Figure 5. - Mobile Transporter track and corner switch arrangement.

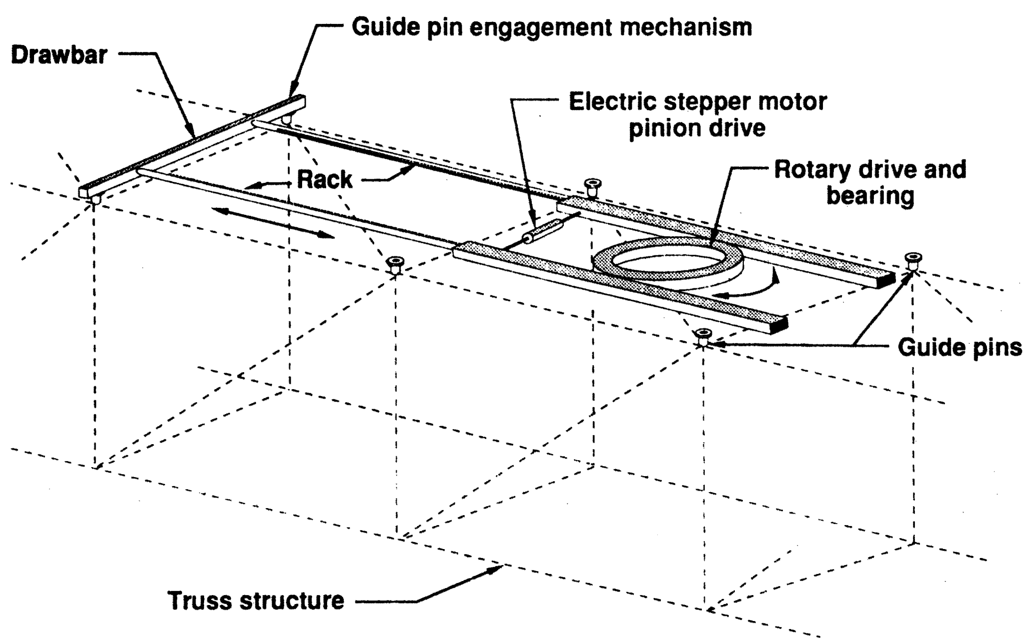


Figure 6. - Mobile Transporter push/pull drive system arrangement.

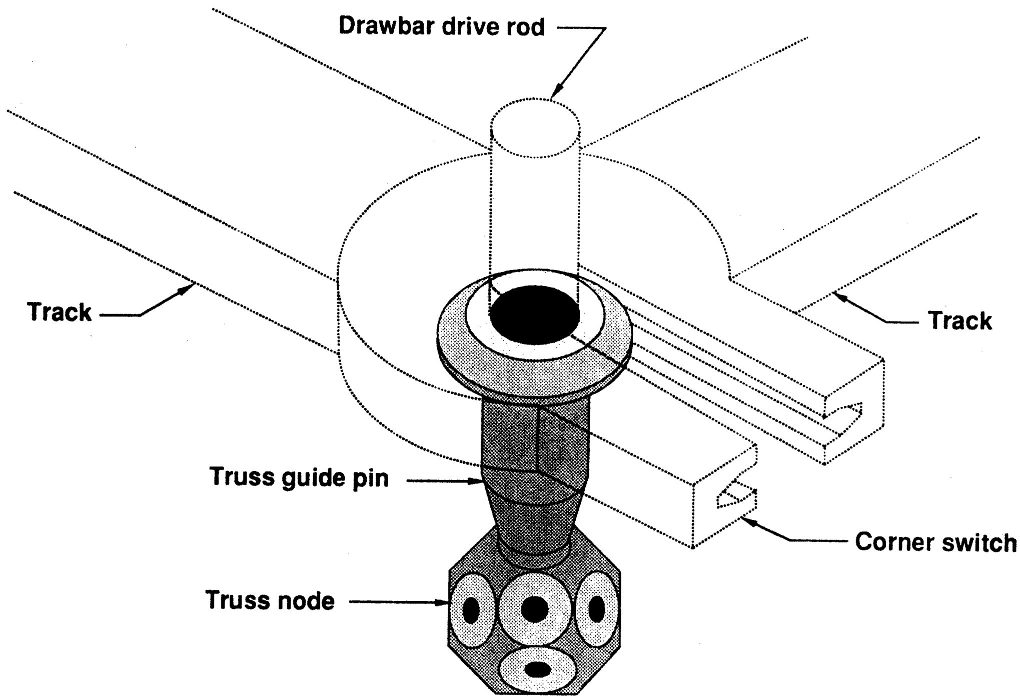


Figure 7. - Mobile Transporter corner switch, guide pin, and drive rod arrangement.

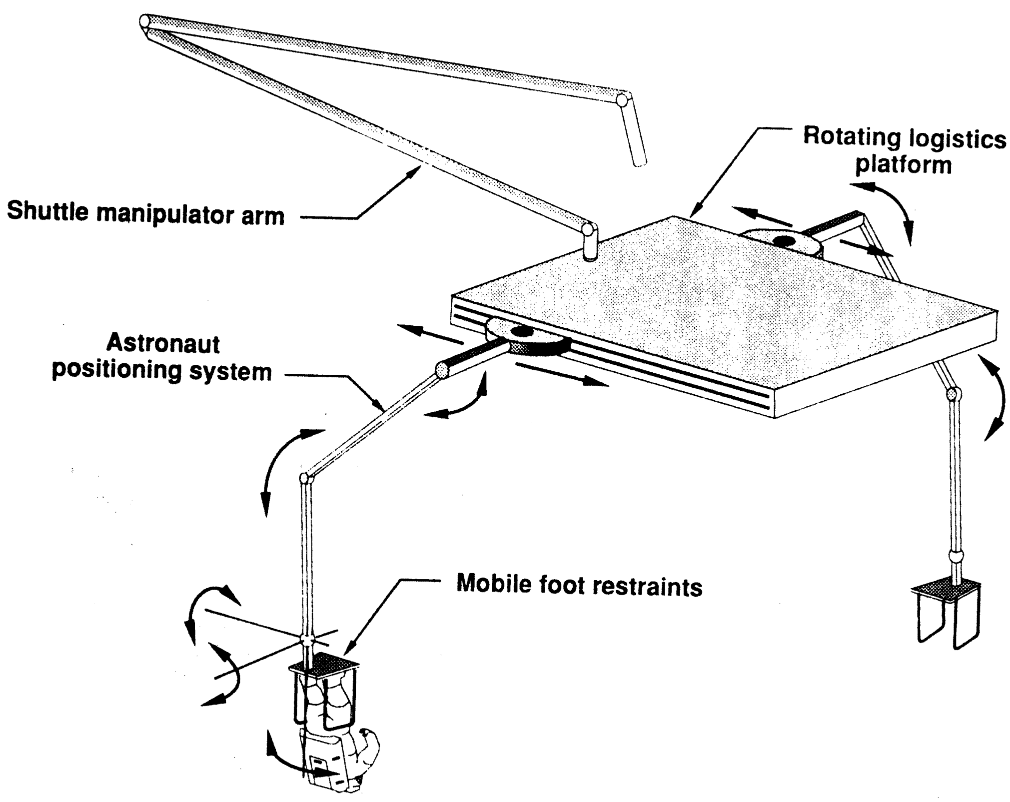


Figure 8. - Mobile Transporter logistics platform with remote manipulator arm and astronaut positioning system arrangement.

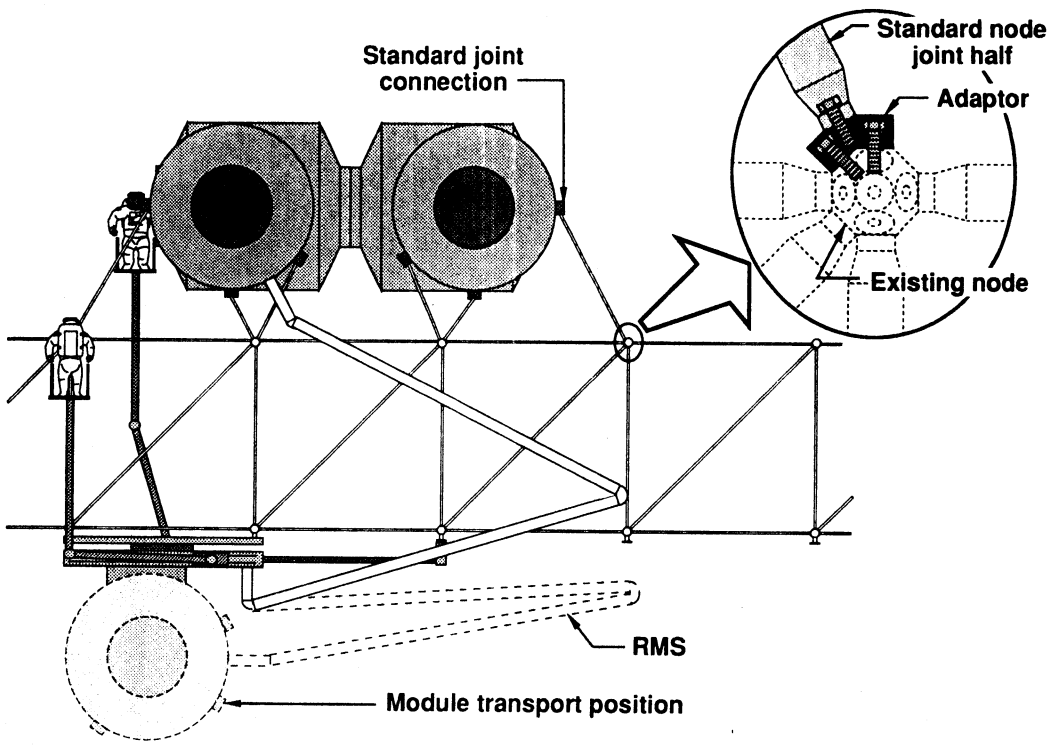


Figure 9. - Installation of modules using Mobile Transporter and Space Station truss elements.

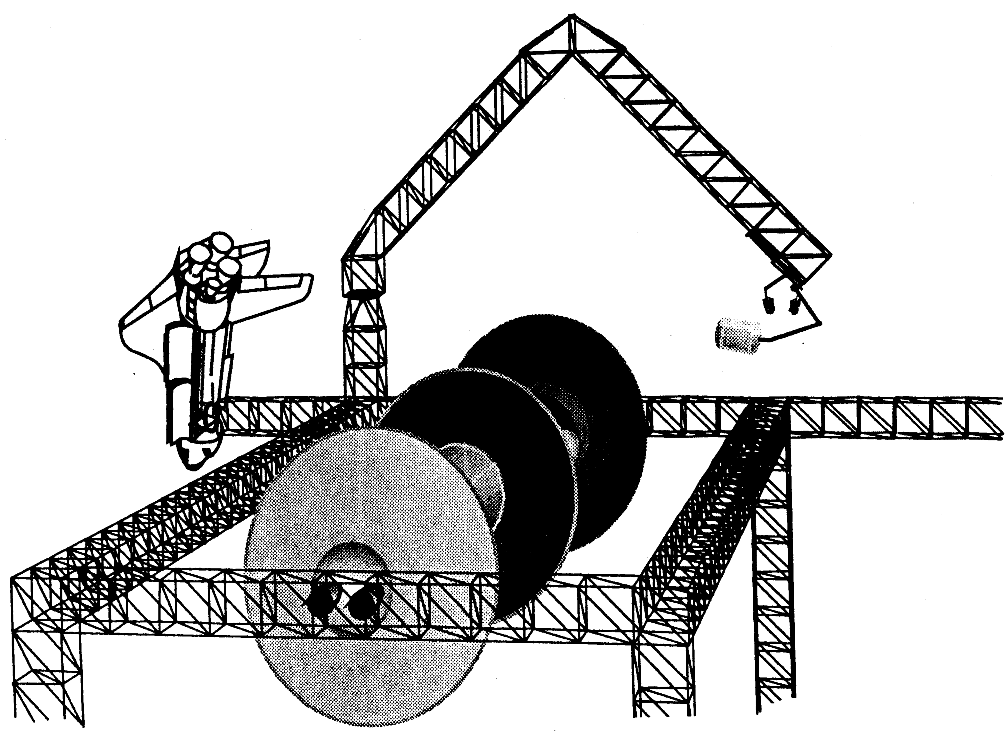


Figure 10. - Interplanetary spacecraft assembly using Mobile Transporter and Space Crane.

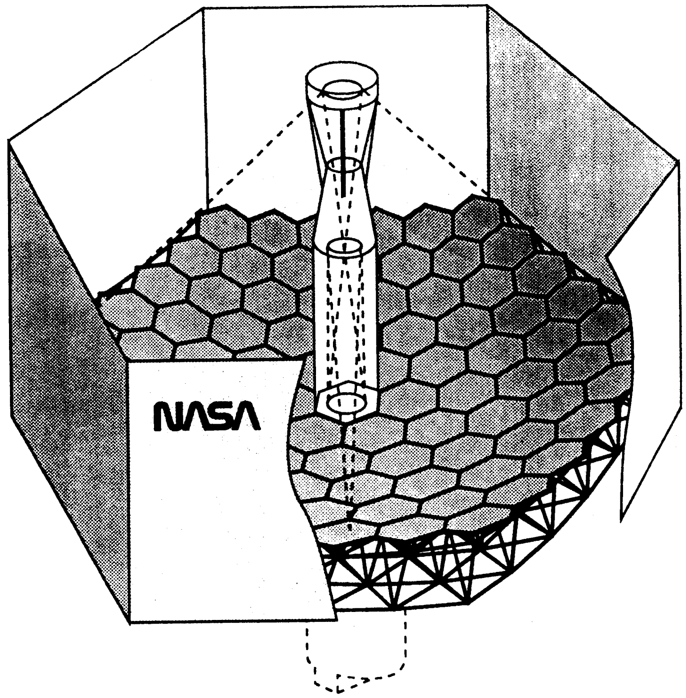


Figure 11. - Proposed Large Submillimeter Astronomical Laboratory.

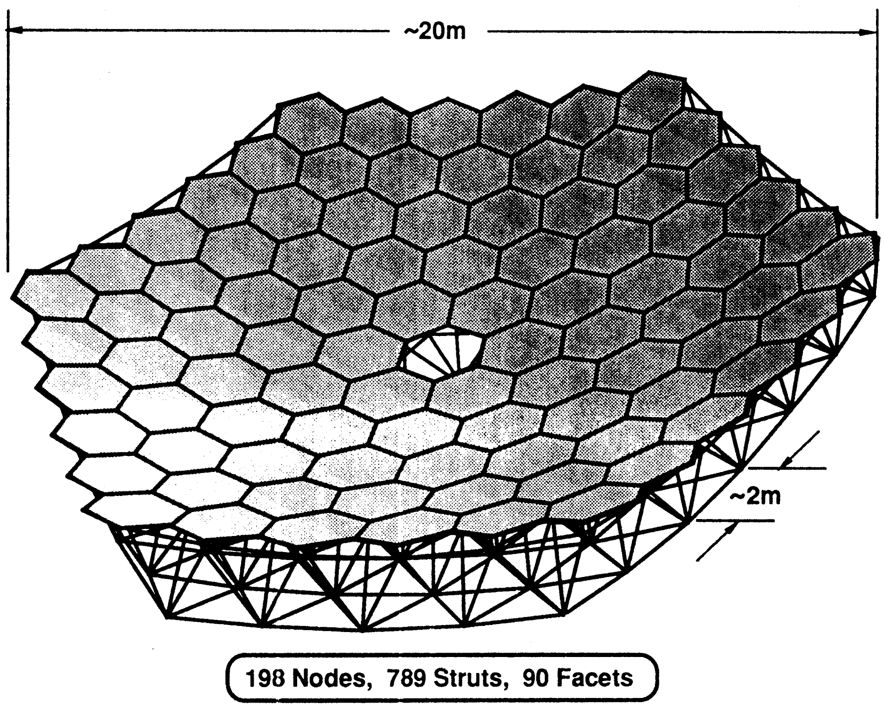


Figure 12. - Geometry of Precision Segmented Reflector for submillimeter astronomical laboratory.

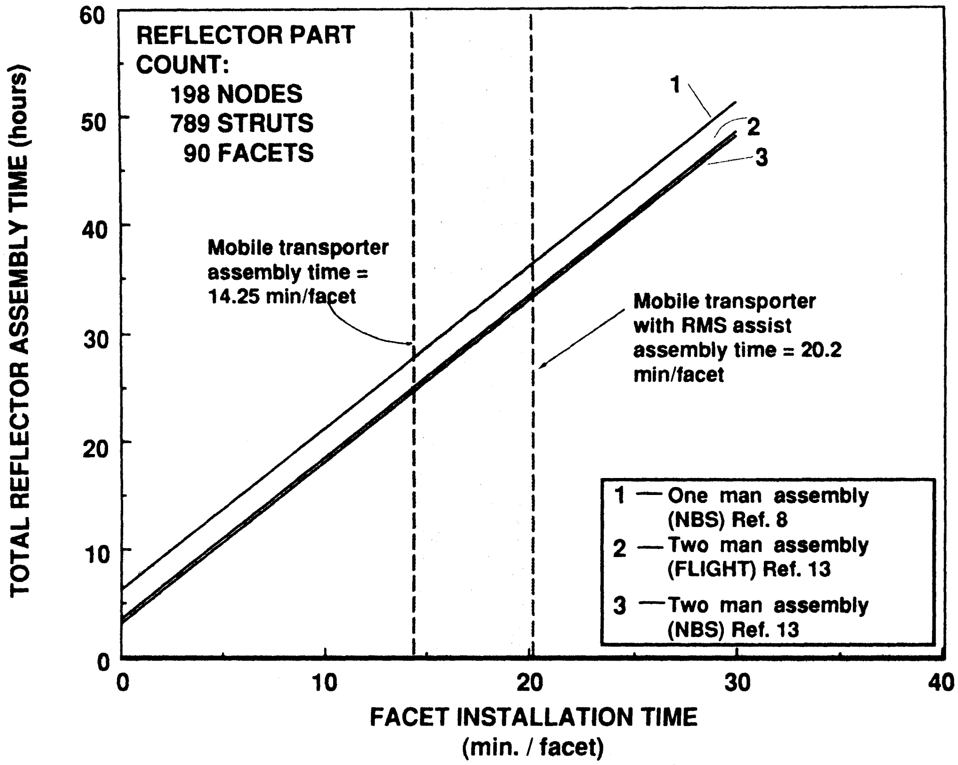


Figure 13. - Estimated time required to assemble the Precision Segmented Reflector for submillimeter astronomical laboratory.

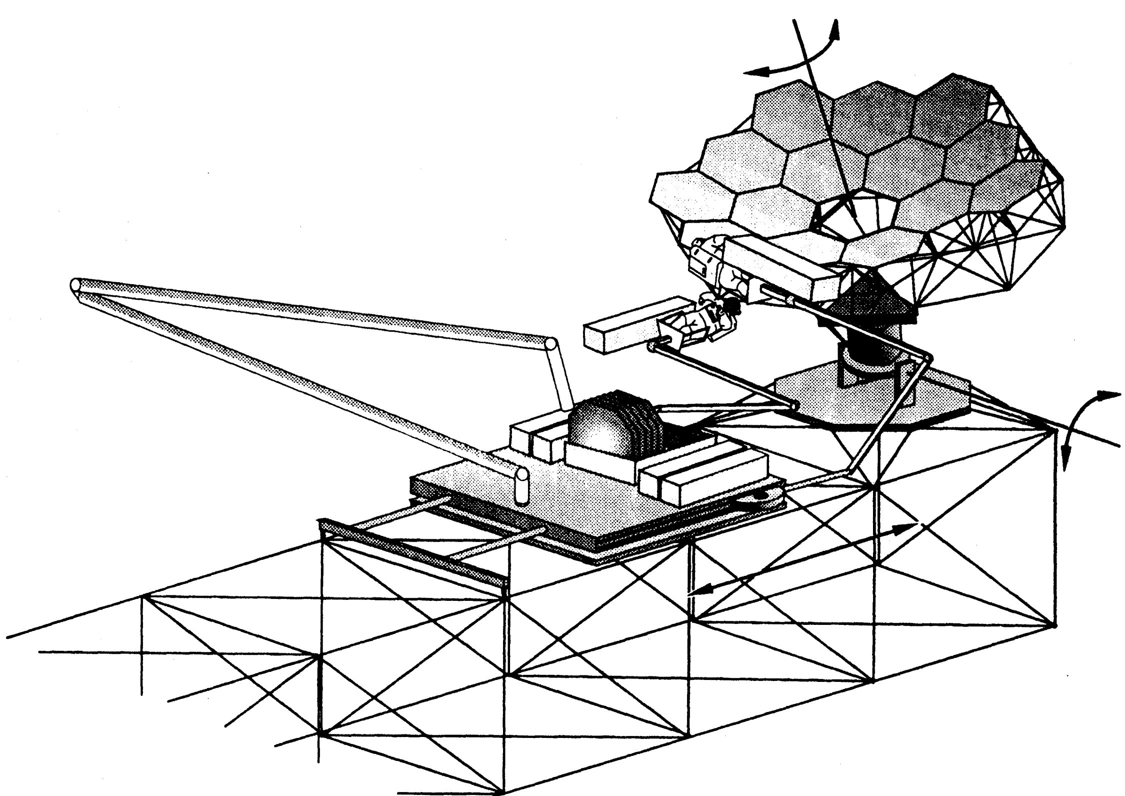


Figure 14. - Construction of Precision Segmented Reflector from Mobile Transporter

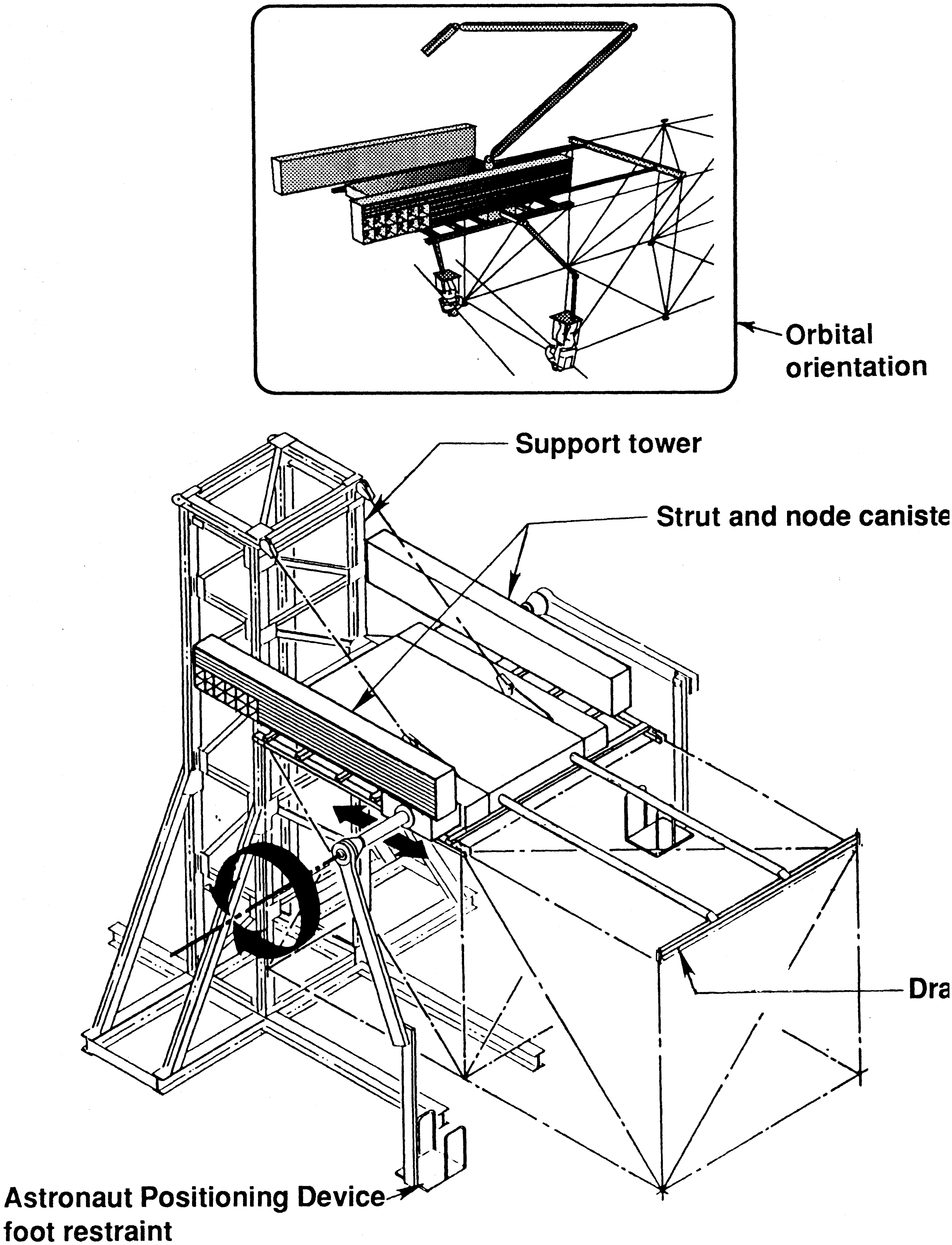
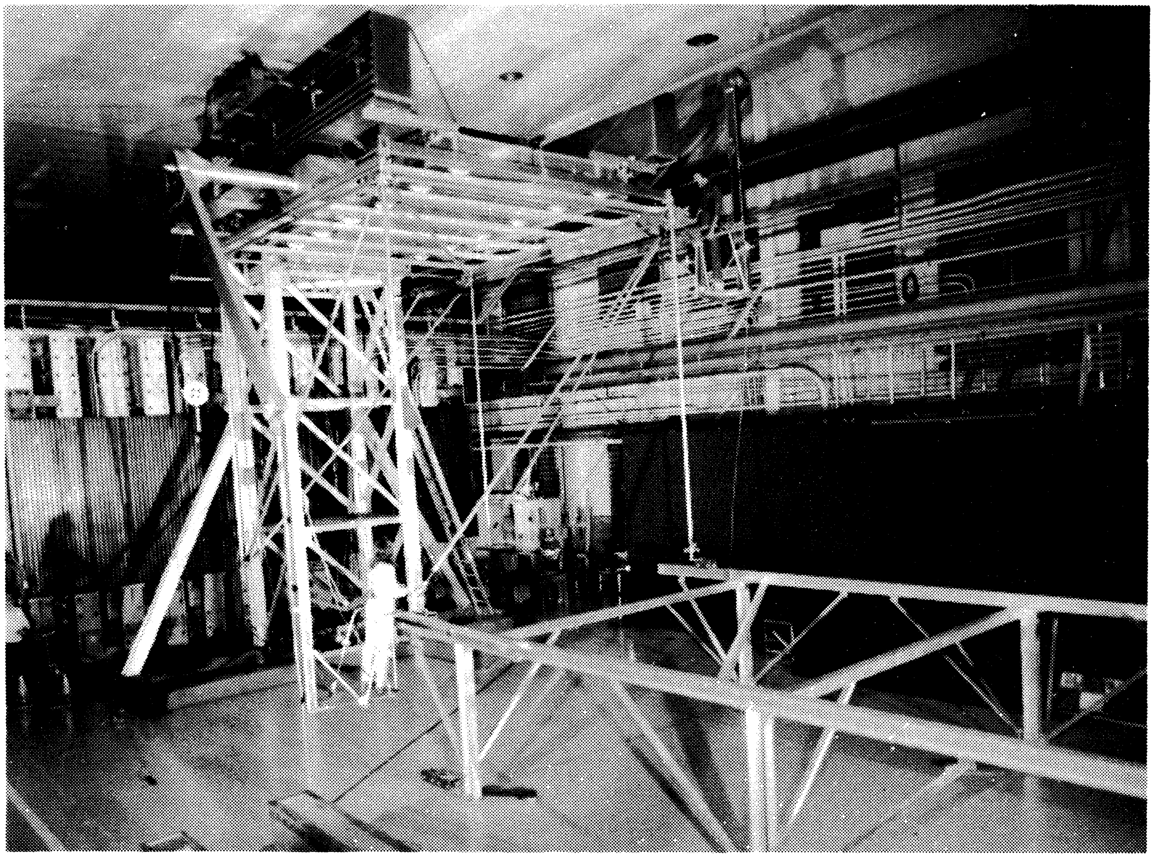
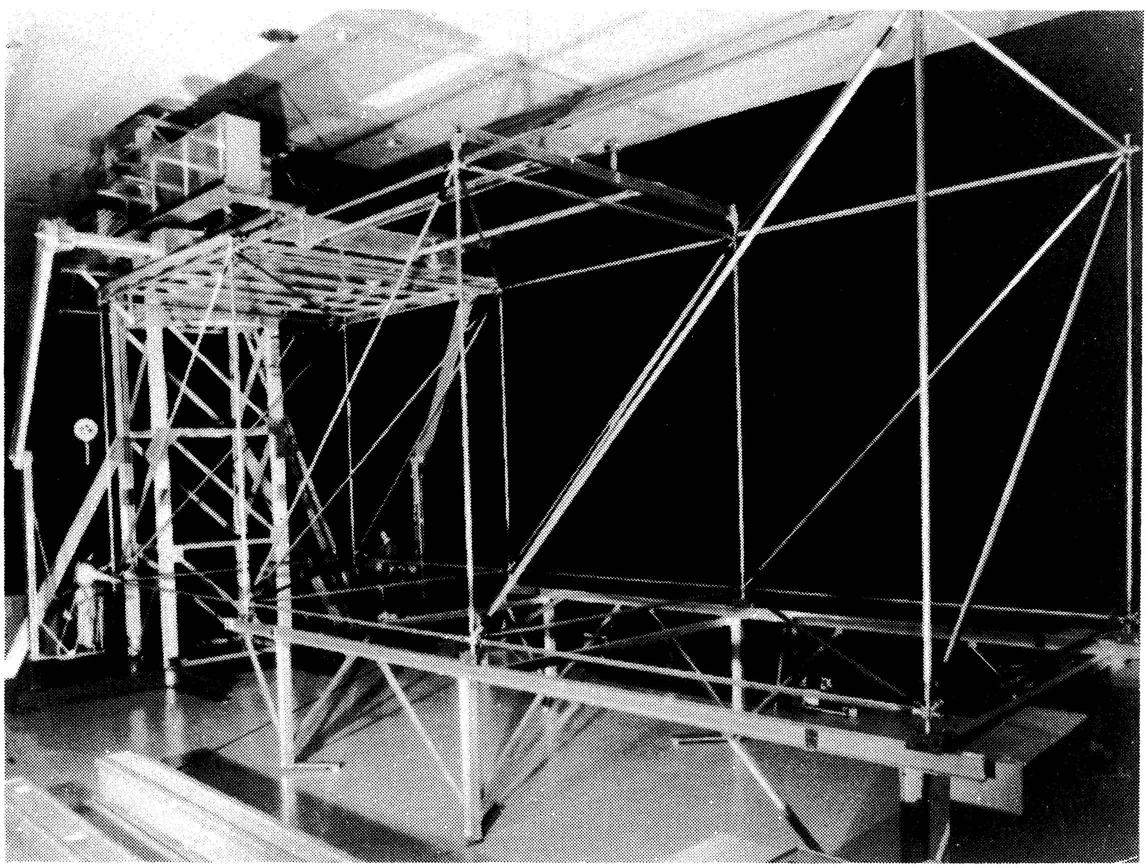


Figure 15. - Schematic of Mobile Transporter test article.

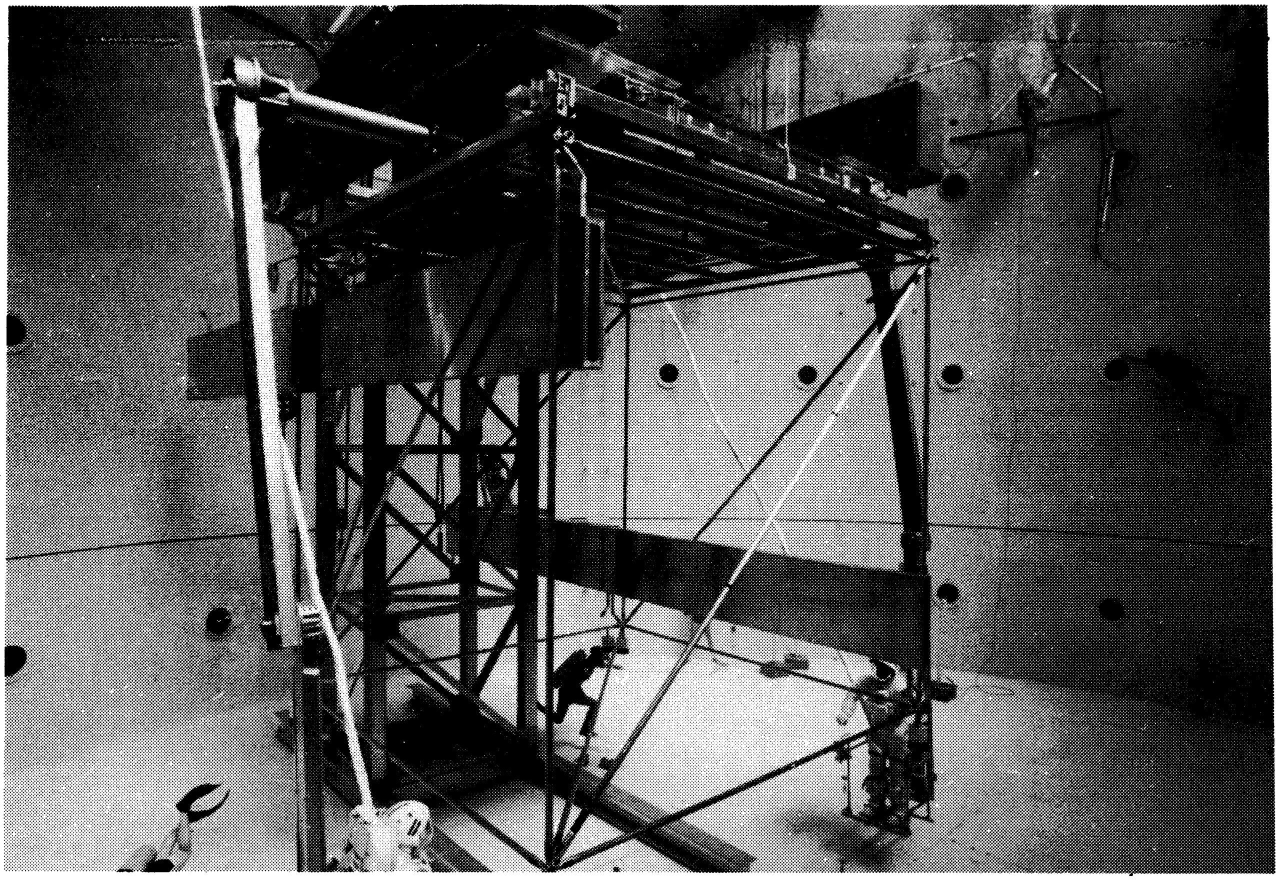


(a) Assembly of first bay.



(b) Three-bay truss completed.

Figure 16. - Three bay Space Station truss assembly in 1-g with Mobile Transporter.



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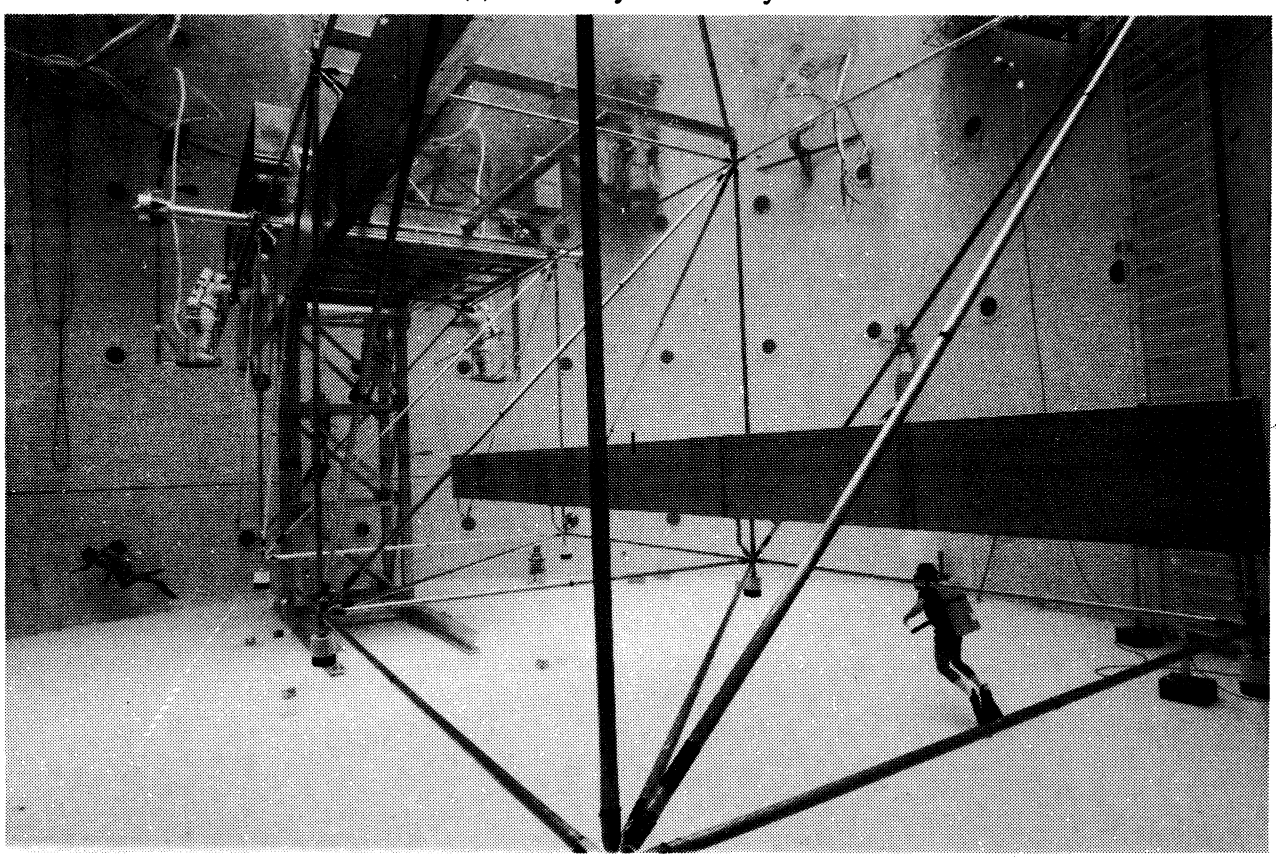

(b) Assembly of third bay.

Figure 17. - Neutral Buoyancy truss assembly and integration of utility trays by test subjects in pressure suits, using the Mobile Transporter.

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National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-101514		

4. Title and Subtitle	5. Report Date
The Versatility of a Truss Mounted Mobile Transporter for In-Space Construction	November 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Harold G. Bush, Mark S. Lake, Judith J. Watson and Walter L. Heard, Jr.	
	10. Work Unit No.
	506-43-41-02
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665-5225	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Mobile Transporter (MT) evolution from early erectable structures assembly activities is detailed in this paper. The MT operational features which are required to support astronauts performing on-orbit structure construction or spacecraft assembly functions are presented and discussed. Use of the MT to perform a variety of assembly functions is presented. Estimated EVA assembly times for a precision segmented reflector approximately 20-meters in diameter are presented. The EVA/MT technique under study for construction of the reflector (and the entire spacecraft) is illustrated. Finally, the current status of development activities and test results involving the MT and Space Station structural assembly are presented.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space Construction EVA Assembly Mobile Transporter	Unclassified - Unlimited Subject Category - 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	18	A02

NASA FORM 1626 OCT 86